

INLET TECHNOLOGY

Paul Kutschenreuter
General Electric
Cincinnati, OH

At hypersonic flight Mach numbers, particularly above $Mo = 10$, the inlet compression process is no longer adiabatic, real gas chemistry takes on extra importance, and the combined effects of entropy layer and viscous effects lead to highly nonuniform flow profile characteristics at the combustor entrance.

At such conditions, "traditional" inlet efficiency parameters such as defined Figure 1 can be unnecessarily cumbersome and/or somewhat lacking in their ability to appropriately characterize the inlet flow and to provide insight into resulting implications on propulsion system performance. Recent experience suggests that use of Inlet Entropy increase as a hypersonic inlet efficiency parameter has much to offer.

Table 1 illustrates that for a specified value of the inlet efficiency parameter, that scramjet inlet "throat" properties such as are required for use in subsequent propulsion cycle calculations are somewhat easier to calculate when Inlet Entropy increase is used.

As used in high Mach number scramjet cycle calculations, Figure 2 illustrates that the derivative of propulsion system performance with inlet performance tends to be more linear with Inlet Kinetic Energy Efficiency and Inlet Entropy increase. This is helpful in design trade studies.

Figure 3 illustrates the use of Inlet Entropy increase in the Mollier diagram format of Figure 1, except that lines of constant contraction ratio rather than lines of constant static pressure are used. Consequently, continuity is satisfied, which is helpful in parametric studies.

Figure 9 displays a "window of opportunity" on the Mollier diagram as bounded by an upper and lower inlet contraction ratio levels and Inlet Entropy increase. Superimposed are the impact of inviscid shock losses for ideal 3, 4, and 5 oblique shock compression inlet systems. "Viscous & Bluntness Margin" then become the region to the right.

Figure 10 documents that the inlet shock losses are linear only with Inlet Entropy increase. Such linearity is helpful to inlet designers in evolving initial flowpath geometry for specific performance objectives.

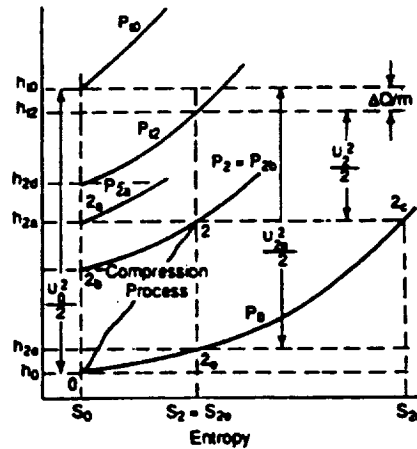
Figure 11 illustrates how the previous 1-D approach can be extended to nonuniform scramjet inlet throat profiles by rewriting the conservation equations in boundary layer integral parameter format.

Figure 12 presents parametric hypersonic inlet performance based on this flow profile nonuniformity approach. Note in the first panel that the Inlet Entropy increase is also linear with friction and leading edge bluntness drag losses. Since the conservation equations have been

solved, the corresponding amount of inlet heat loss is also known; and should this be absorbed by the slush hydrogen fuel mixture, the corresponding amount of available fuel heat sink used is also known.

The Figure 13 summary for a number of calculations such as in the previous figure indicates that the Reynolds Analogy seems to apply quite well here. Consequently, inlet heat loss is also reasonably linear with Inlet Entropy increase.

Thus we have seen that use of Inlet Entropy increase as an inlet efficiency parameter for hypersonic applications seem to provide some advantages over the use of the more traditional parameters.



$$\text{Kinetic Energy Efficiency} = \eta_{KE} = \frac{h_{2c} - h_{2a}}{h_{2c} - h_0} = \frac{U_{2c}^2}{U_0^2}$$

$$\text{Process Efficiency} = \eta_{PD} = \frac{h_2 - h_{2a}}{h_2 - h_0}$$

$$\text{Static Pressure Efficiency} = \eta_P = \frac{P_2}{P_{2a}}$$

$$\text{Compression Efficiency} = \eta_c = \frac{h_{2a} - h_0}{h_2 - h_0}$$

Figure 1. Inlet Performance Parameters (Reference 1).

Table I. Calculation of Combustor Inlet Conditions Compared.

Kinetic Energy Efficiency, η_K	Stagnation Pressure Efficiency, η_P	Process Efficiency, η_{PD}	Compression Efficiency, η_C	Energy Increase $\frac{q_0}{h}$
<ol style="list-style-type: none"> 1. $U_b = \sqrt{\eta_K} U$ 2. Guess T_b 3. $h_b + \frac{U_b^2}{2} \stackrel{?}{=} h_a + \frac{U^2}{2}$ 4. Guess T_1 5. Guess P_1 6. $U_1 = \frac{U_a A_a P_a \sqrt{\gamma_a T_a}}{A_1 P_1 \sqrt{\gamma_1 T_1}}$ 7. $S_1 \stackrel{?}{=} S_b$ 8. $h_1 + \frac{U_1^2}{2} \stackrel{?}{=} h_a + \frac{U^2}{2}$ 	<ol style="list-style-type: none"> 1. Guess P_b 2. Guess T_1 3. $P_1 = \eta_P P_b$ 4. $U_1 = \frac{U_a A_a P_a \sqrt{\gamma_a T_a}}{A_1 P_1 \sqrt{\gamma_1 T_1}}$ 5. $h_1 + \frac{U_1^2}{2} \stackrel{?}{=} h_a + \frac{U^2}{2}$ 6. Guess T_b 7. $h_b \stackrel{?}{=} h_1$ 8. $S_b \stackrel{?}{=} S_1$ 	<ol style="list-style-type: none"> 1. Guess P_1 2. Guess T_1 3. $U_1 = \frac{U_a A_a P_a \sqrt{\gamma_a T_a}}{A_1 P_1 \sqrt{\gamma_1 T_1}}$ 4. $h_1 + \frac{U_1^2}{2} \stackrel{?}{=} h_a + \frac{U^2}{2}$ 5. Guess T_b 6. $q_{in} \stackrel{?}{=} \frac{h_1 - h_b}{h_1 - h_a}$ 7. $S_1 \stackrel{?}{=} S_b$ 	<ol style="list-style-type: none"> 1. Guess P_1 2. Guess T_b 3. $S_b \stackrel{?}{=} S_1$ 4. Guess T_1 5. $U_1 = \frac{U_a A_a P_a \sqrt{\gamma_a T_a}}{A_1 P_1 \sqrt{\gamma_1 T_1}}$ 6. $h_1 + \frac{U_1^2}{2} \stackrel{?}{=} h_a + \frac{U^2}{2}$ 7. $q_b \stackrel{?}{=} \frac{h_b - h_1}{h_1 - h_a}$ 	<ol style="list-style-type: none"> 1. Guess T_1 2. Guess P_1 3. $U_1 = \frac{U_a A_a P_a \sqrt{\gamma_a T_a}}{A_1 P_1 \sqrt{\gamma_1 T_1}}$ 4. $\frac{S_1 - S_a}{R} \stackrel{?}{=} \frac{q_0}{R}$ 5. $h_1 + \frac{U_1^2}{2} \stackrel{?}{=} h_a + \frac{U^2}{2}$

Figure 2. Specific Impulse versus Inlet Efficiency.

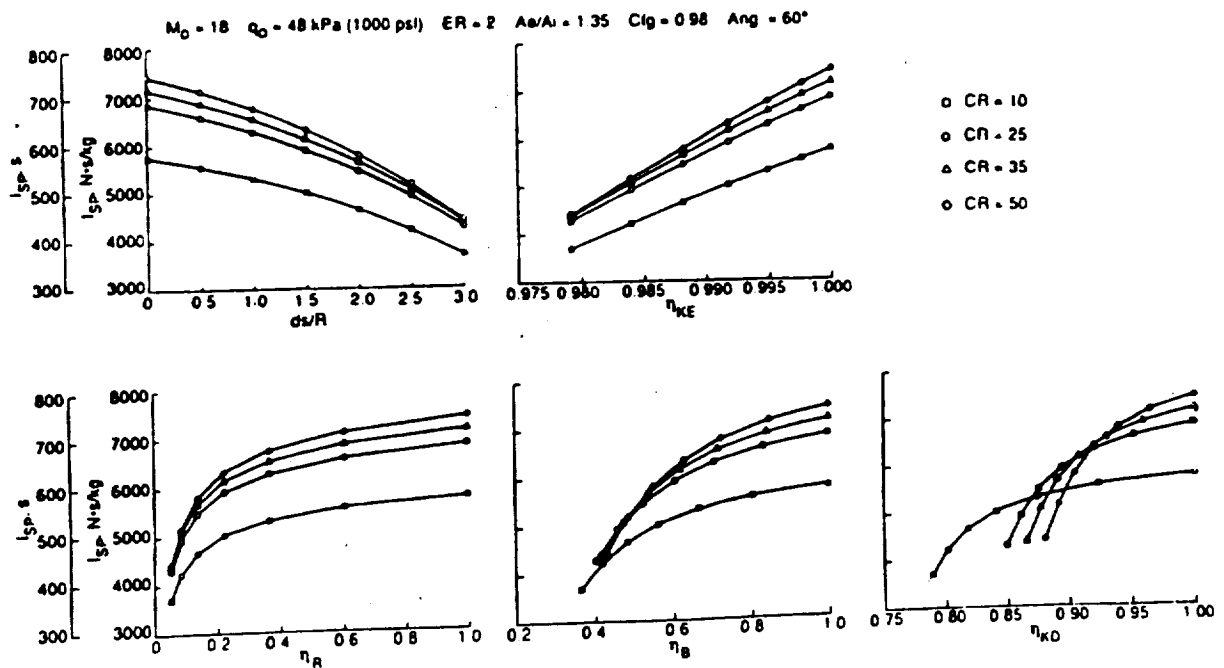


Figure 3. "Mollier" Diagram with Inlet Contraction Ratio Lines.

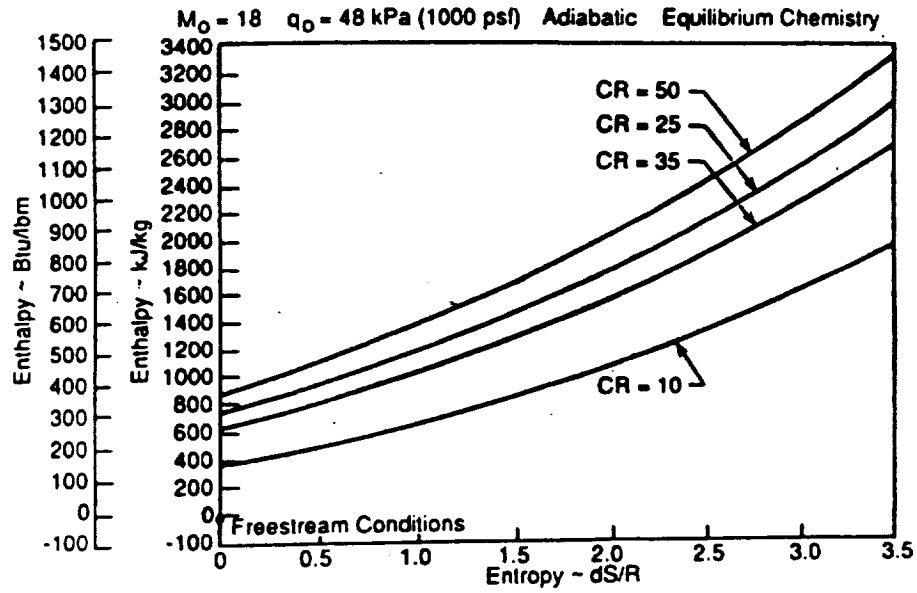
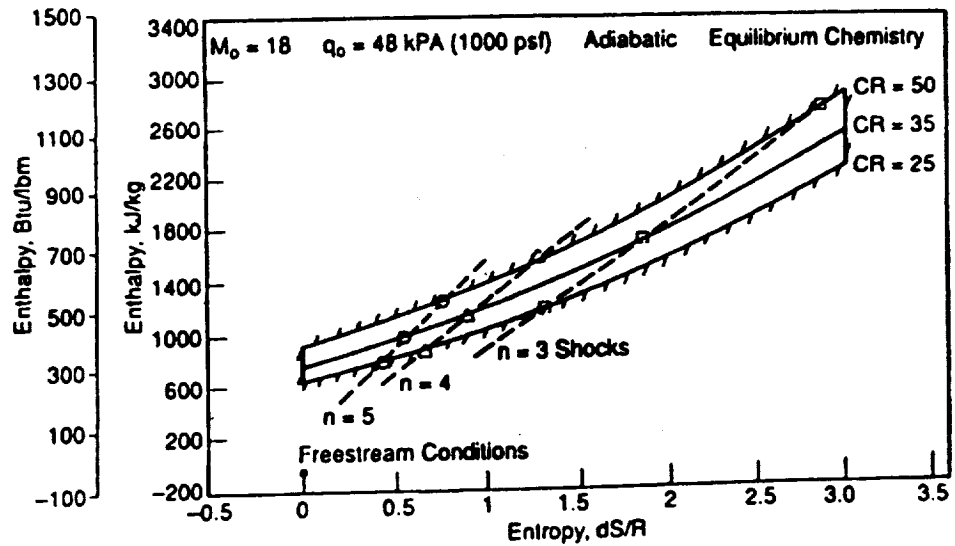
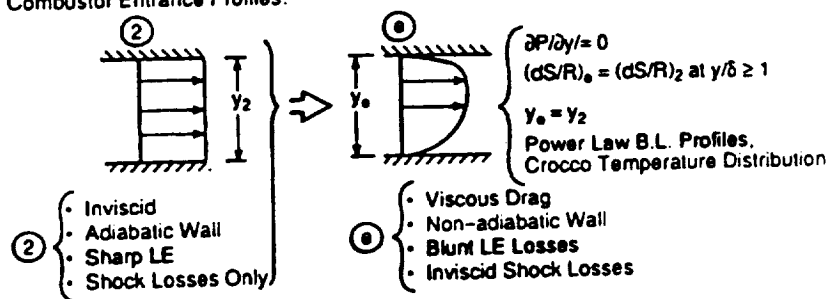


Figure 9. Optimum Shock Inlet Results.



$M_0 = 18$ $q_0 = 48 \text{ kPa (1000 psf)}$ $CR = 56.8$ Equilibrium Chemistry
4 Equal Strength Inlet Shocks

Combustor Entrance Profiles:



Continuity: $\delta y_2 = \left[1 - \sqrt{\frac{\gamma_2 T_0}{\gamma_0 T_2} \frac{P_2 M_2}{P_0 M_0}} \right] (\delta' / \delta)$

Momentum:

$$P_2(1 + \gamma_2 M_2^2) - \Sigma \left(\frac{D_{FR} + D_{BL}}{A_2} \right) = P_o (1 + \gamma_o M_o^2) - \frac{\delta}{\gamma_2} P_o \gamma_o M_o^2 \left(\frac{\delta}{\delta} + \frac{\theta}{\delta} \right)$$

Energy: $y/\delta \geq 1: C_{p2} T_2 + \frac{U_2^2}{2} = C_{p0} T_0 + \frac{U_0^2}{2}$

$$y/\delta < 1: \quad \frac{h_{Loss}}{h_{T0}} = 1 - \left(1 - \frac{\delta}{y_2} \frac{\delta}{\delta}\right) \left\{1 - \frac{\delta}{y_2} \left[\frac{\delta}{\delta} + \frac{\theta}{\delta} \left(1 - \frac{h_w}{h_{T2}}\right)\right]\right\}$$

Figure 12. Inlet Performance Nomograph.

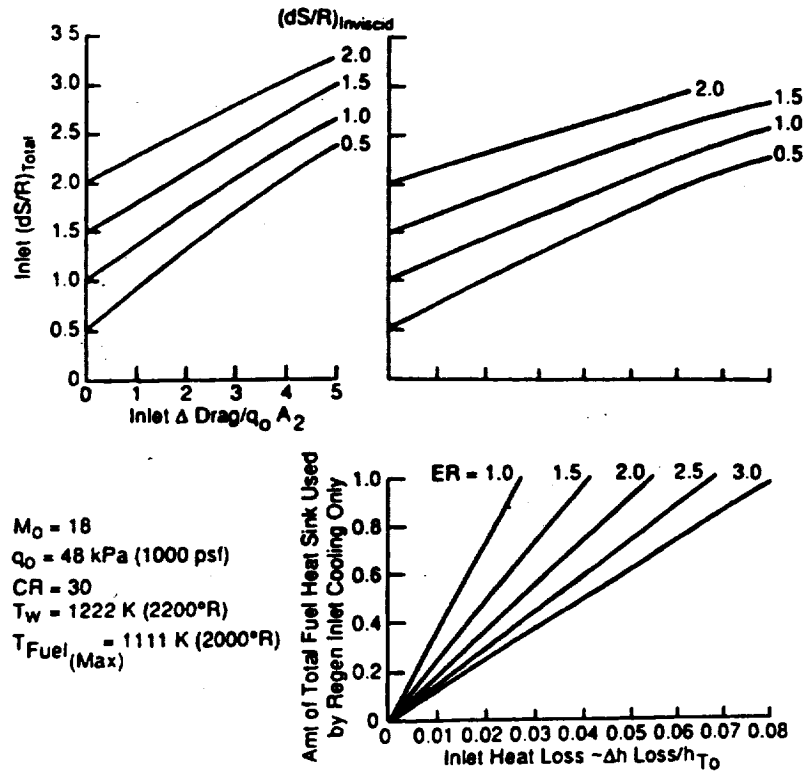


Figure 13. "Modified" Reynolds Analogy Comparison.

